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Title: Magneto-Inertial Fusion and the Plasma Liner Experiment (PLX)

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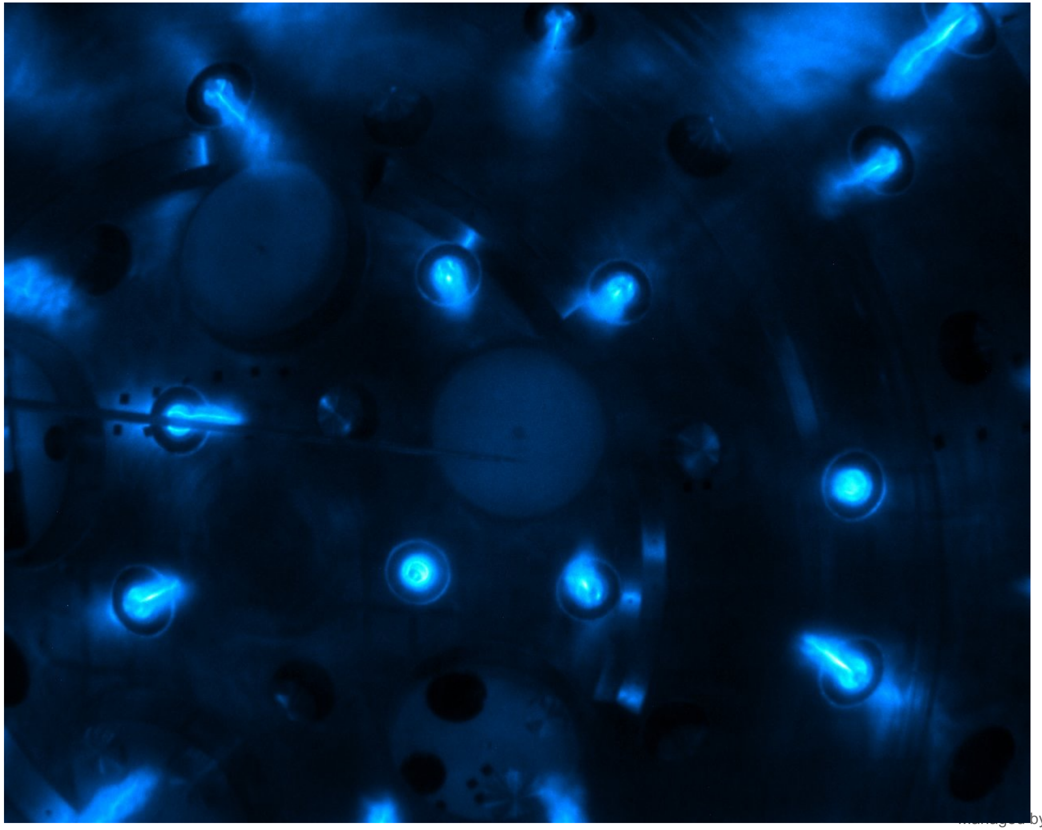
Magneto-Inertial Fusion and the Plasma Liner Experiment (PLX)



Samuel Langendorf,
P-4, Los Alamos National Laboratory

Physics Cafe
June 24th, 2021

Los Alamos National Laboratory EST. 1943
HYPERJET FUSION CORPORATION
HYPERV TECHNOLOGIES CORP
THE UNIVERSITY OF NEW MEXICO
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE
arpa·e CHANGING WHAT'S POSSIBLE
NNSA National Nuclear Security Administration

PLX Team and Collaborators

- **LANL**
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  - Tom Byvank
  - Feng Chu
  - John Dunn
  - Levi Grantz
- **Hyper-V / HyperJet**
  - PI Doug Witherspoon
  - Edward Cruz
  - Andrew Case
  - Marco Luna
- **University of New Mexico**
  - PI Mark Gilmore
  - Andrew Lajoie
  - Lucas Webster
- **University of Alabama Huntsville**
  - PI Jason Cassibry
  - Sumontro Sinha
  - Aalap Vyas
- **ARPA-E BETHE Capability Teams**
  - URochester, PI Petros Tzeferacos
  - Virginia Tech, PI Bhuvana Srinivasan
  - UT Austin, PI Craig Michoski

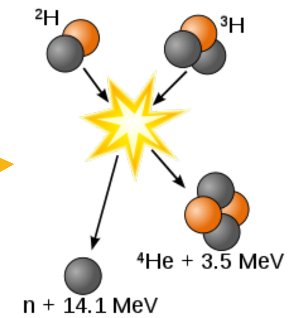
CHANGING WHAT'S POSSIBLE

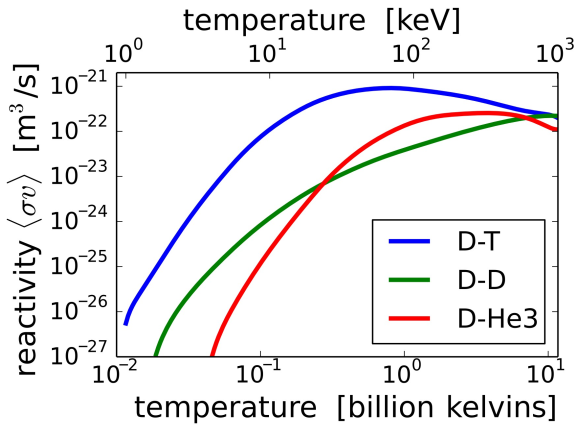
The plasma physics field has long been driven by the pursuit of controlled fusion energy, an energy “holy grail”

- Process that powers the sun and other active stars
- Carbon-free
- Plentiful, power-dense fuel, e.g., 1 m^3 seawater contains 33 g deuterium, equivalent to 400,000 kg of coal*
- No long-half-life waste**
- high temperatures required

10 keV ~= 100,000,000 K

Deuterium-Tritium fusion reaction:





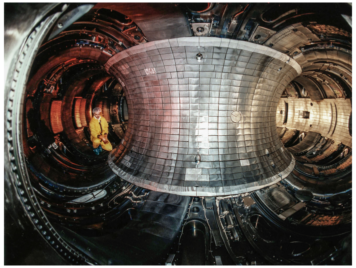
Magneto-inertial fusion (MIF) is an alternative "hybrid" approach to fusion energy

- Magnetic confinement – trap / levitate a fusion fuel plasma with strong magnetic fields, heat to fusion conditions with RF, beams, etc.

- Inertial confinement – Compress and heat the fusion fuel rapidly enough to outrun thermal losses and ignite the fuel

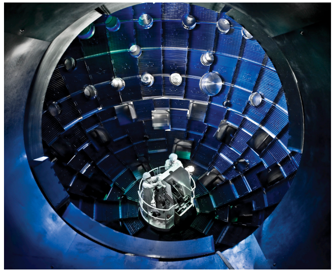
- Magneto-inertial confinement – Blend of the two above approaches, compress and heat a magnetized target plasma

Tokamaks, (Stellarators), (Mirrors),



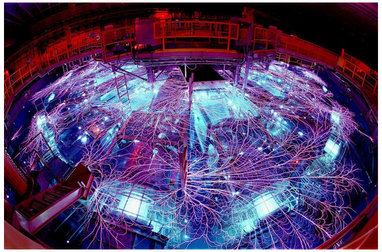
TFTR at Princeton Plasma Physics Lab

High-Power Laser Facilities:



National Ignition Facility (NIF) at LLNL

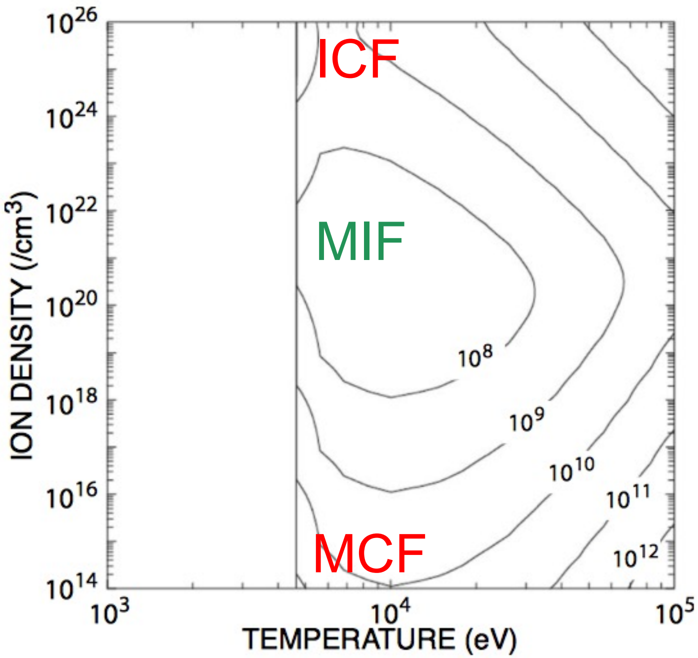
Electrical Pulsed Power Machines:



Z Machine at Sandia National Labs

MIF is a potential low-cost sweet spot in thermonuclear parameter space

Nominal Breakeven-Class Facility Cost[1] ($)



- Cost goes up with facility stored energy and effective heating power[1]

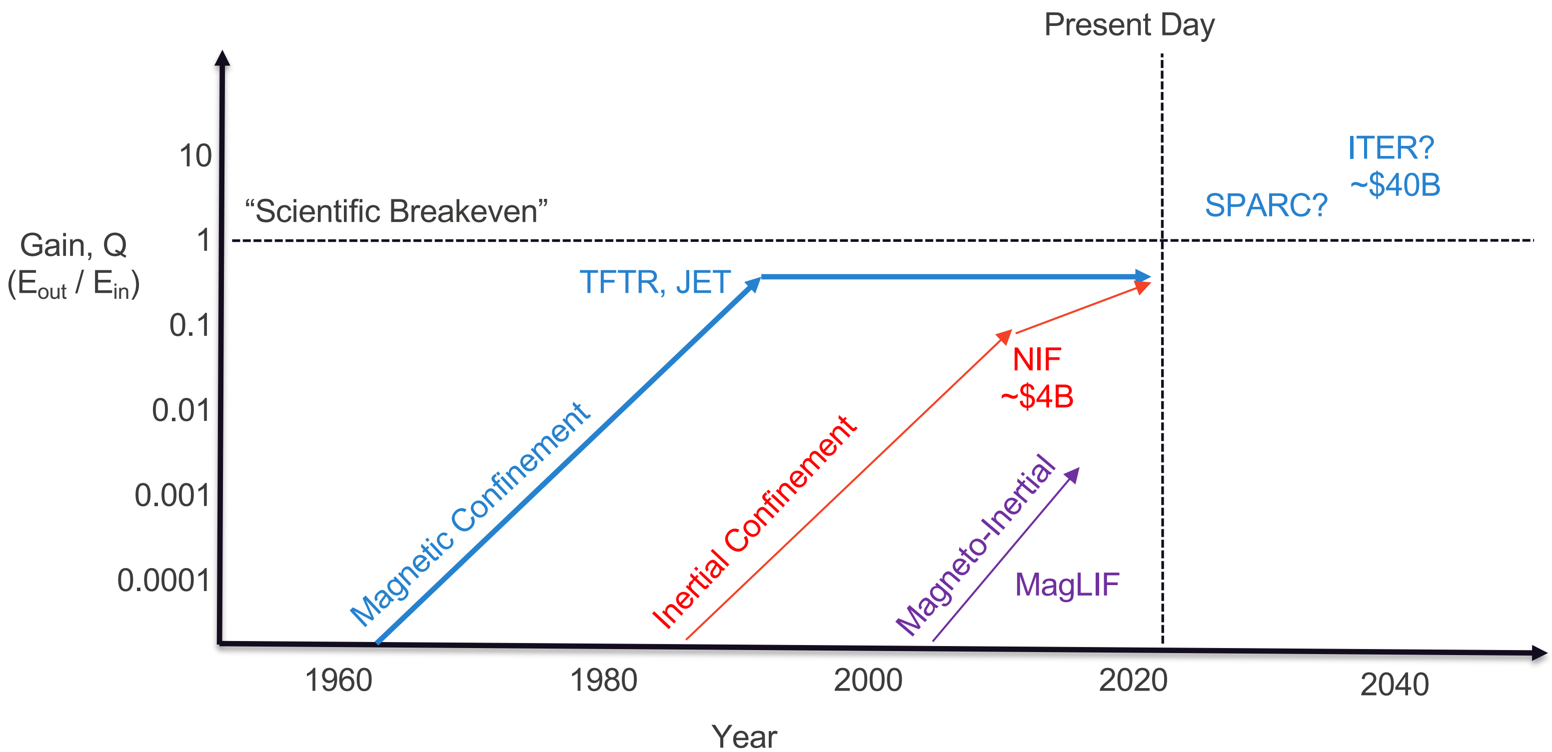
$$\text{Cost} = c_1 E_{PLAS} + c_2 P_{HEAT} \approx \frac{\$10\text{B}}{E_{ITER}} E_{PLAS} + \frac{\$3\text{B}}{P_{NIF}} P_{HEAT}$$

- Assuming Bohm-like magnetic insulation of energy transport, a cost minimum exists around $n \sim 10^{20}$ - 10^{22} cm^{-3}, $B \sim 1$ MG

1. Lindemuth, Irvin R., and Richard E. Siemon. "The fundamental parameter space of controlled thermonuclear fusion." American Journal of Physics 77.5 (2009): 407-416.

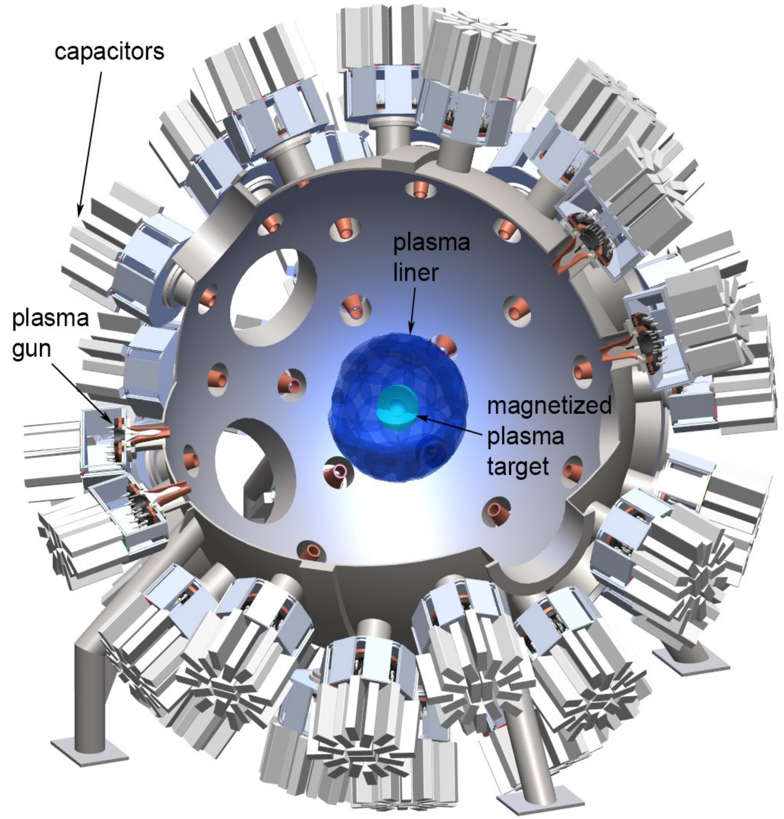
Fusion progress has historically slowed down when facilities reach the multi-billion dollar scale

(Approximate:)



The Plasma Liner Experiment (PLX) at LANL investigates a “reactor-friendly” MIF approach

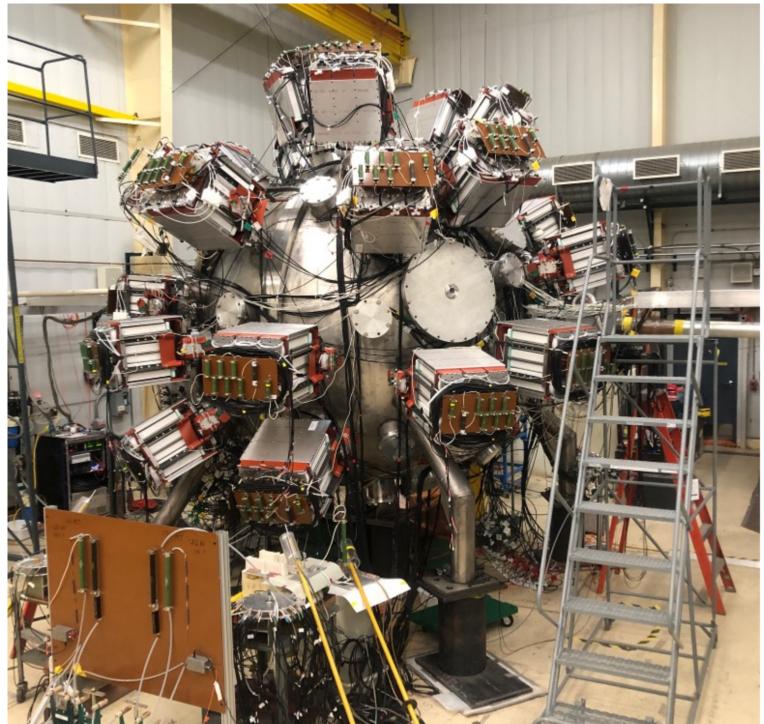
- A magnetized plasma target is injected into the target chamber, and then compressed and heated by a heavy high-velocity plasma liner, assembled from discrete jets.
  - Spherical compression
  - All-gas / all-plasma architecture -- no repetitive hardware destruction
  - Physical “standoff” distance from burn location
  - Compatible with high-efficiency driver technologies and high-beta magnetized targets

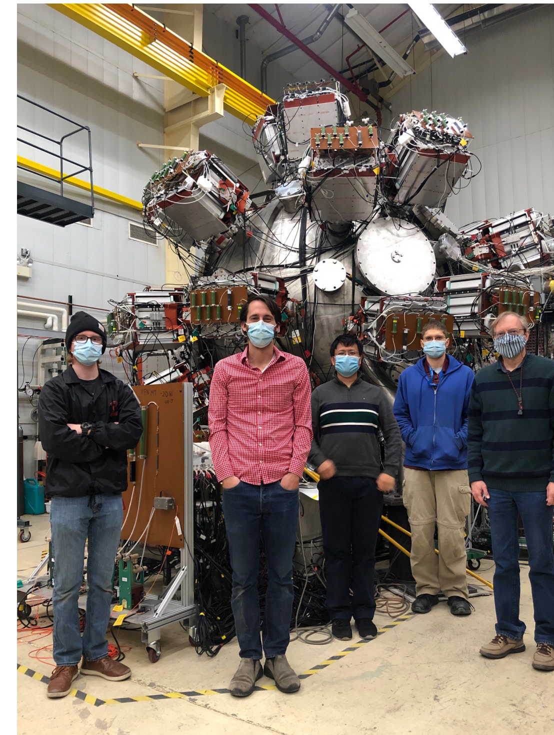


Thio, YC Francis, et al. "Plasma-jet-driven magneto-inertial fusion." *Fusion Science and Technology* 75.7 (2019): 581-598.
Hsu, Scott C., et al. "Spherically imploding plasma liners as a standoff driver for magnetoinertial fusion." *IEEE Trans. Plasm. Sci.* 40.5 (2012): 1287-1298.

The Plasma Liner Experiment (PLX) at Los Alamos is built to investigate PJMIF

ca. 2017 – ALPHA program



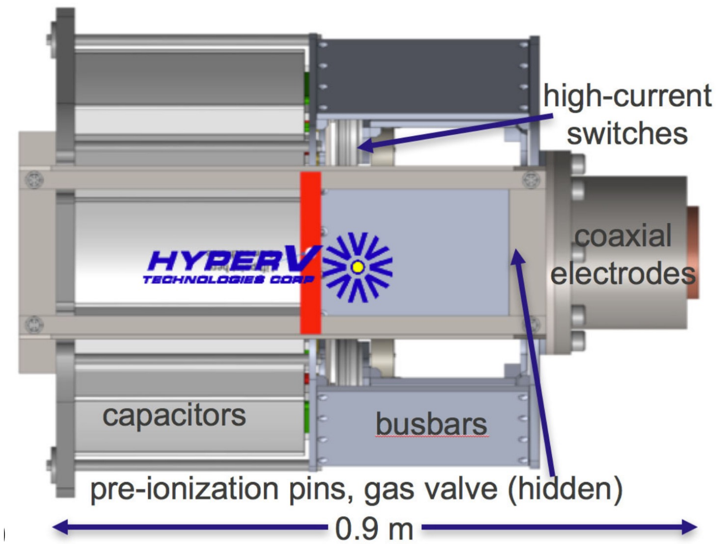


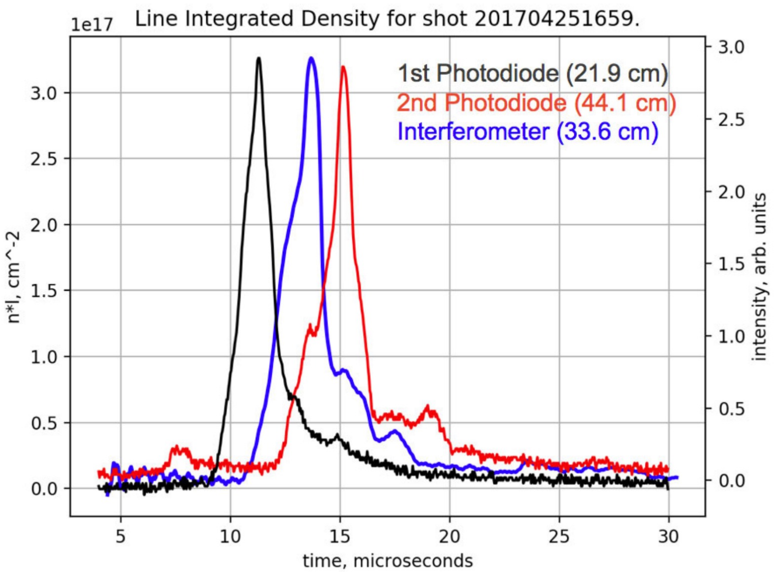
ca. 2020 – building up to spherical liner

Hyper-V Technologies / Hyperjet Fusion have designed and built world-leading plasma guns for PLX / PJMIF

PLX-ALPHA Project:

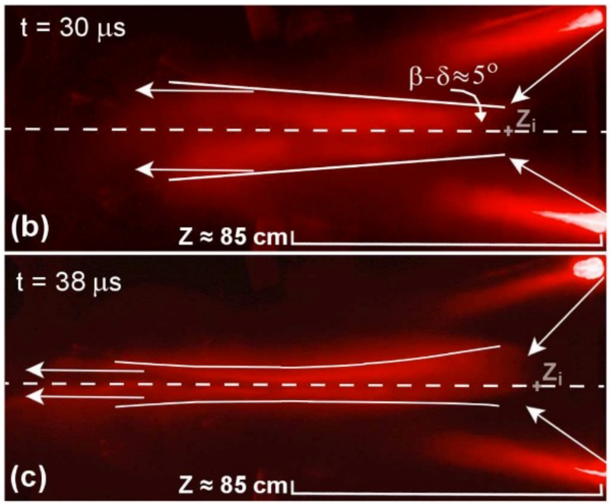
- "Alpha0" and "Alpha1" were prototype dense-plasma coaxial guns
- "Alpha2" gun (below) demonstrated high performance jets
- "HJ1" gun improved the engineering and robustness for 36 gun experiment



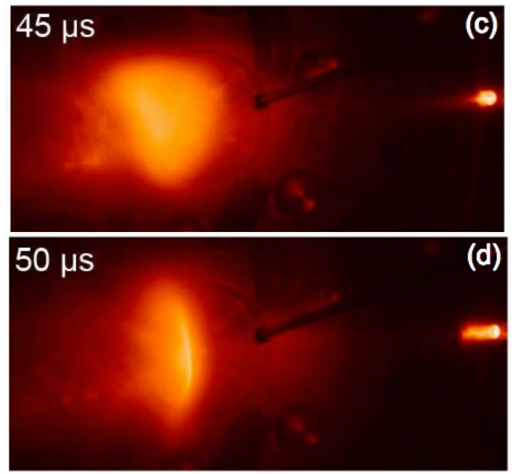


Over the past decade, PLX has explored the merging of discrete supersonic plasma jets and the assembly of a plasma liner

Results from PLX have explored different regimes of plasma jet merging, ranging from collisional plasma shock formation to diffuse interpenetration

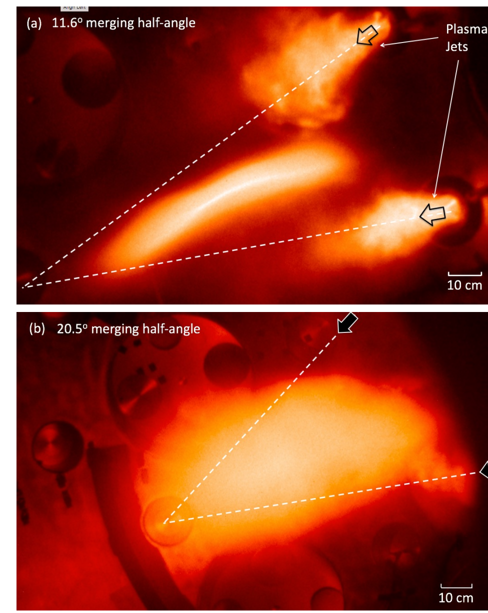


Merritt et al. Phys. Rev. Lett. **111**, 085003 (2013)



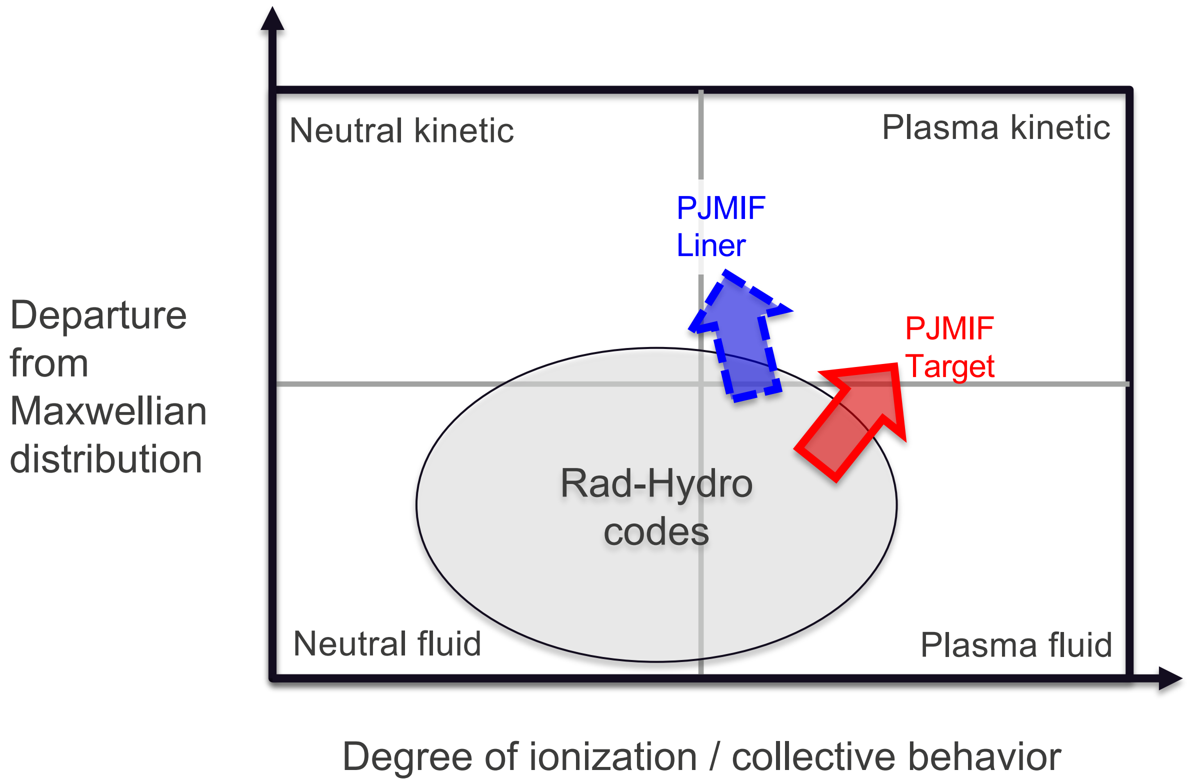
Moser et al. Physics of Plasmas 22.5 (2015): 055707

$$L_i \sim v^4, \overline{Z}^{-4}$$



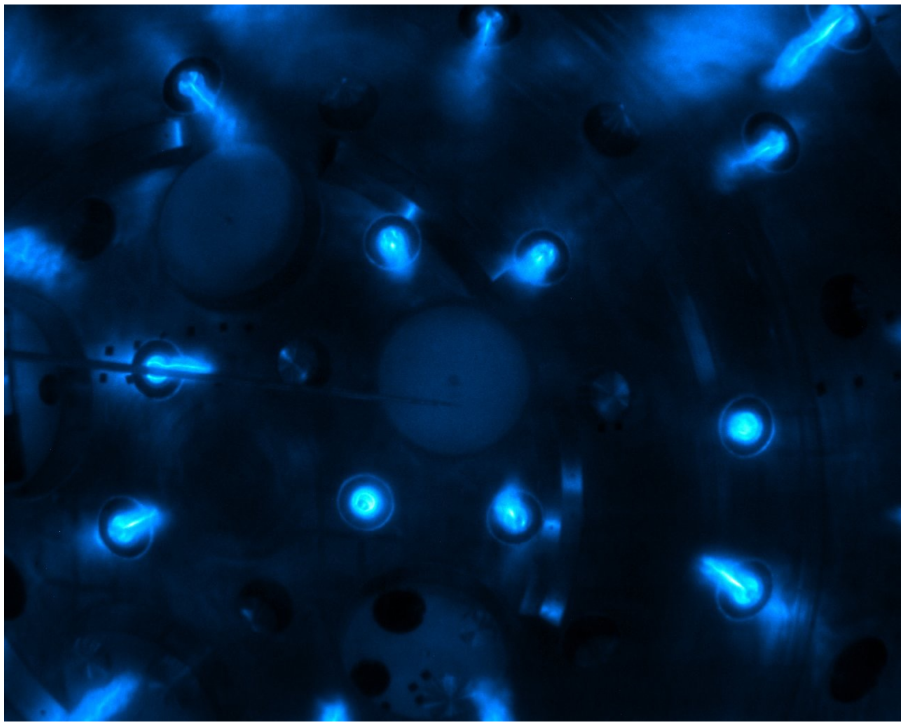
Langendorf et al. Phys. Rev. Lett. *121*(18), 185001.

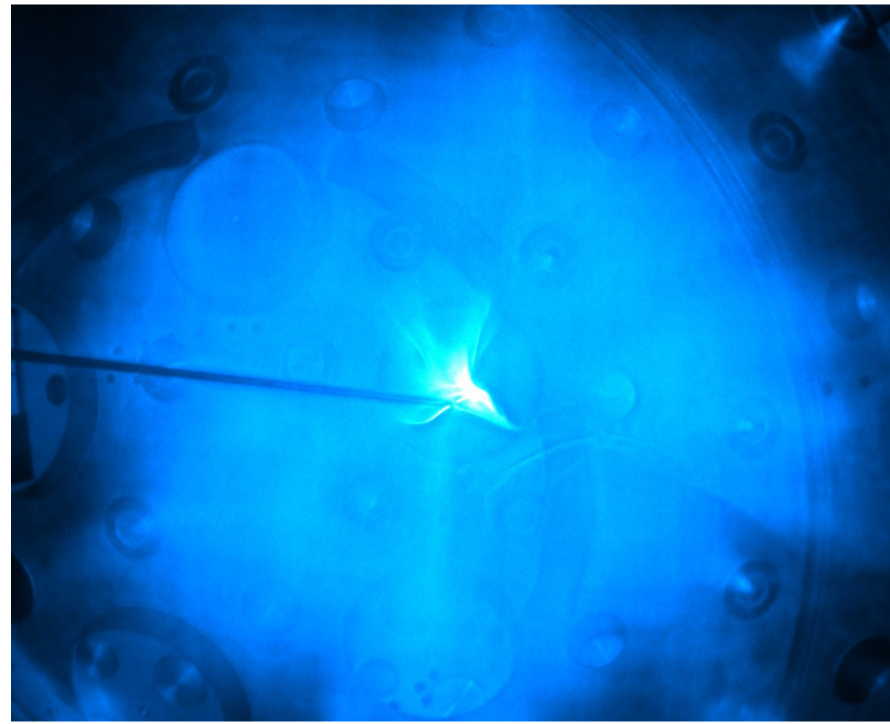
PLX results indicate the need to account for jet interpenetration in PJMIF integrated modeling efforts



First results of spherical liner experiments were obtained early this year

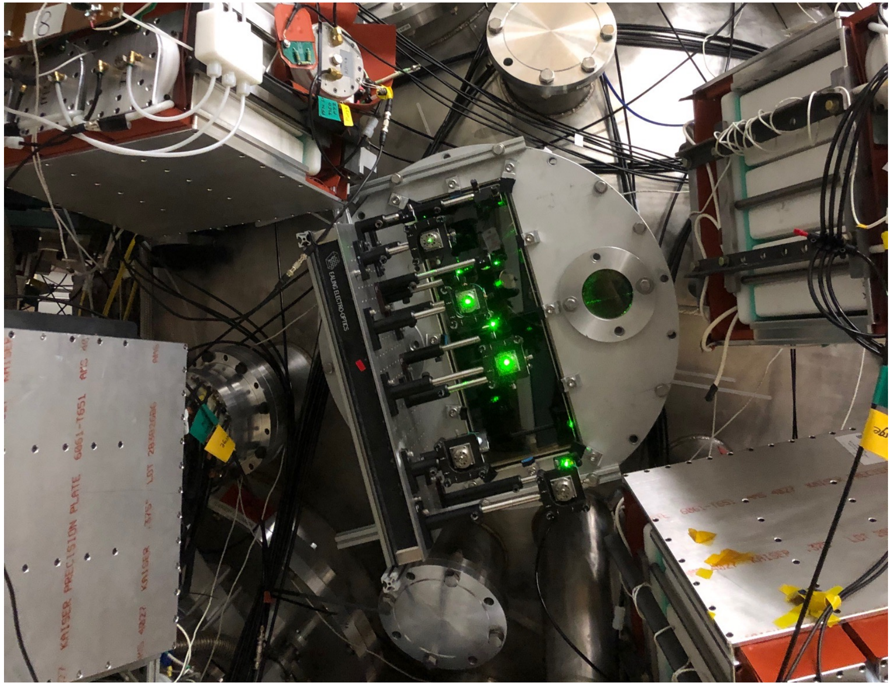
Visible light emission recorded on fast framing cameras:

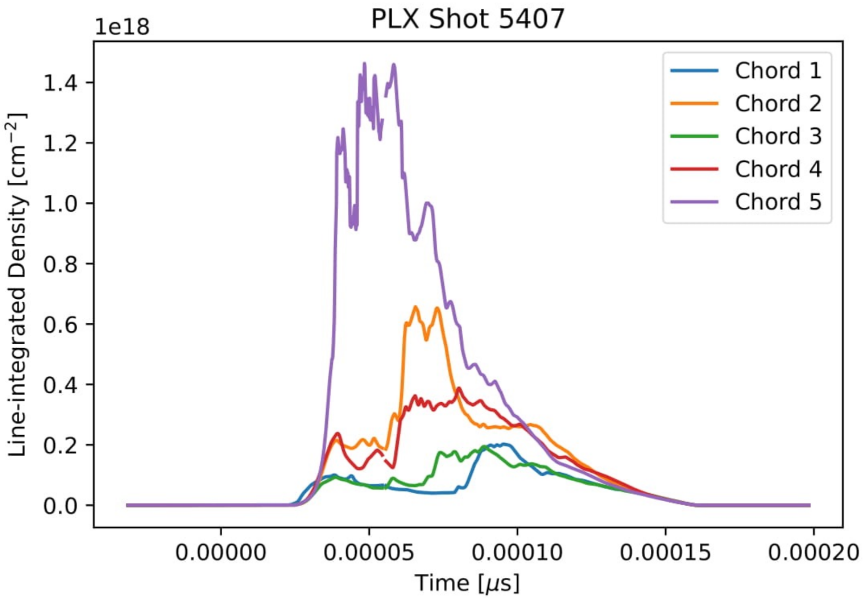




Laser interferometer measures density profile of liner implosion & rebound

5 chords, 3 radii, 13 cm radial spacing

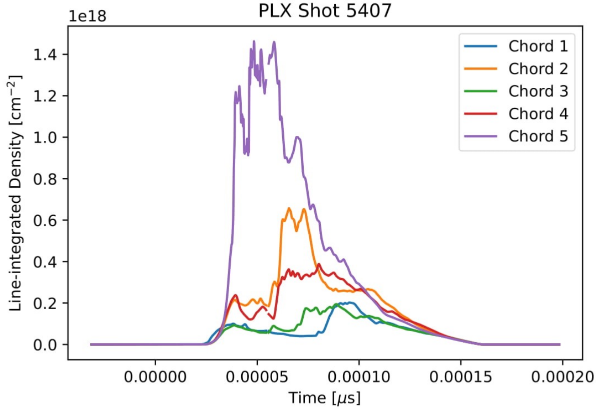




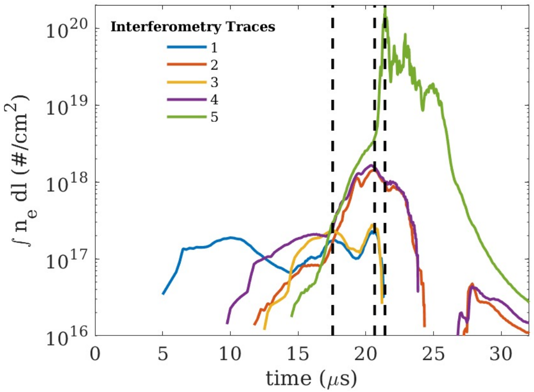
Comparisons with hydrodynamic simulation indicate that interpenetration significant in observed density profile

Simulations c/o Jason Cassibry / Aalap Vyas, Univ. Alabama Huntsville:

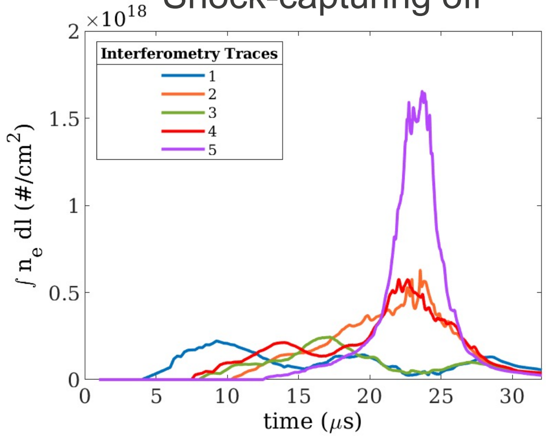
Exp data:



SPH simulation:
Balanced,
Shock-capturing on

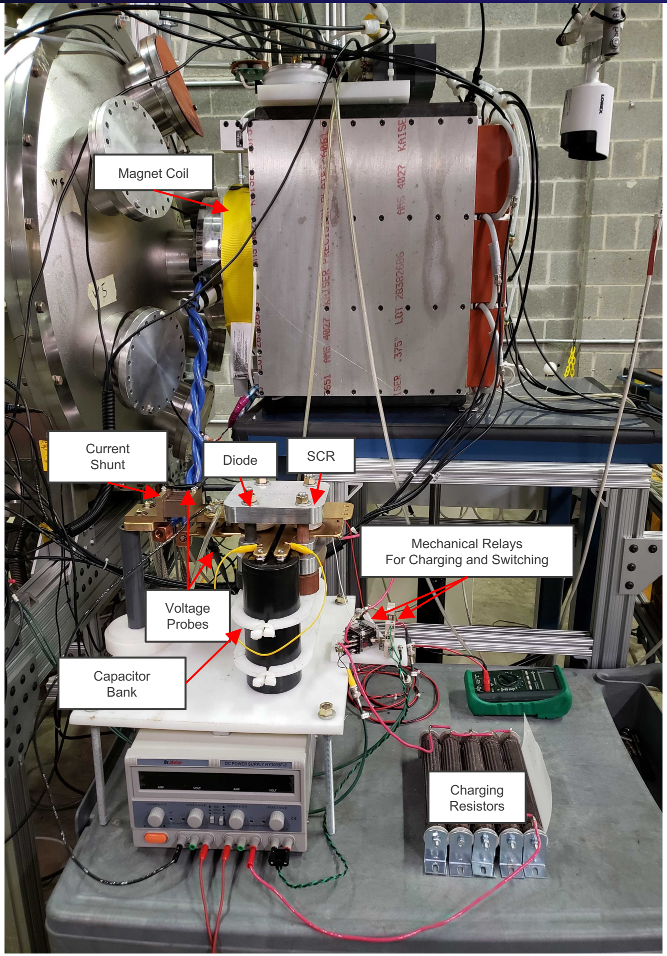


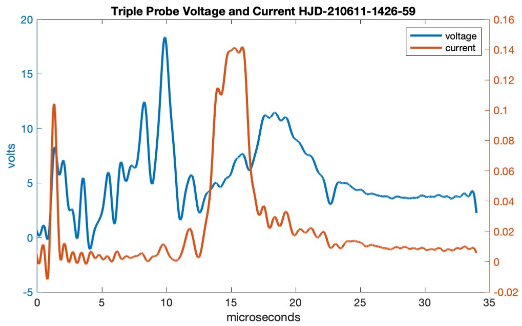
SPH simulation:
Imbalance,
Shock-capturing off

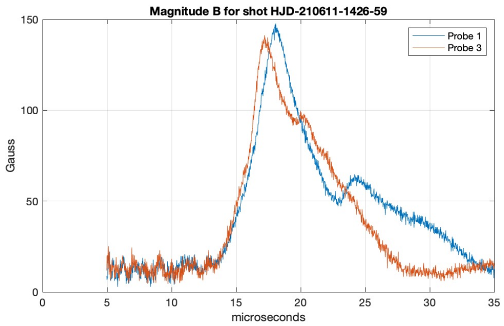


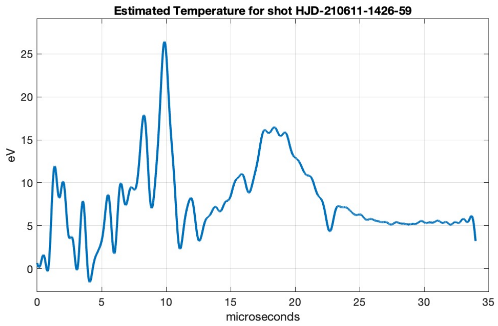
Significant density losses due to plasma interpenetration and “missing” the target
Lower velocity, higher-ion-mass liners may increase performance

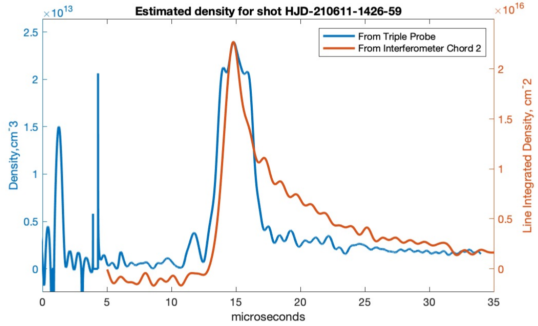
Magnetized target plasma injectors being developed by our collaborators, towards ultimate integrated experiments











ARPA-E BETHE program objectives: develop an integrated subscale PJMIF demonstration (Liner + Target)

Goal: put some data points on these graphs!